

What is claimed is:

1. A method for measuring shear rate at which the viscosity of a fluid is being measured utilizing an acoustic wave device, the acoustic wave device having an input and an output transducers, and having a characteristic relationship between input power, output power, and an acoustic wave amplitude at a selected region between the input and output transducer, the acoustic wave device being coupled to the measured fluid, the method comprising the steps of:
 - applying a predetermined power P_{in} of a harmonic signal having a frequency ω to the input transducer, to impart an acoustic wave at the selected region;
 - measuring output power level P_{out} at the output transducer;
 - using the characteristic relationship, and the input and output power levels, calculating the amplitude of the average acoustic wave imparted to the fluid;
 - measuring viscosity of the fluid to obtain a measured viscosity at the selected region; and,
 - calculating the shear rate of the fluid at the selected region by using the frequency, the viscosity measurement, and the acoustic wave amplitude.
2. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of measuring viscosity is performed utilizing the acoustic wave device.
3. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 2, wherein the step of measuring viscosity is carried out by calculating power insertion loss between the input and output transducers.

4. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 2, wherein the step of measuring viscosity is carried out by measuring phase shift of the imparted signal.
5. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 2, wherein the step of measuring viscosity is carried out by measuring the frequency change required for maintaining a constant phase shift of the imparted signal.
6. A method for measuring shear rate at which the viscosity of a fluid of claim 1, wherein the step of calculating the shear rate is carried out by

utilizing the formula for penetration depth of the acoustic wave into the fluid,

$$\delta = \sqrt{\frac{2\eta}{\omega\rho}}, \text{ where } \omega \text{ is the radian frequency of the applied harmonic wave}$$

having frequency, F, and $\omega=2\pi F$, ρ is the density of the sample liquid. and η is the intrinsic viscosity (Pascal-seconds);

utilizing a design parameter 'C' of the acoustic wave device, to relate the wave displacement 'U', to the average power flow, P_{avg} , as $U = C\sqrt{P_{avg}}$;

and utilizing the frequency of the imparted signal and the foregoing calculations of the penetration depth and the displacement of the crystal face U, to calculate the shear rate as $\dot{\gamma} = \omega U / \delta$.

7. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of calculating the shear rate is carried out using a correlation between the amplitude and the geometric average of the power inserted at the input power and the power sensed at the output transducer.
8. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the selected region contains therewith the geometrical midpoint between the input transducer and output transducer respective geometries.

9. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of measuring viscosity is carried out utilizing the power insertion loss between the input and output transducers.
10. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of measuring viscosity is carried out utilizing phase shift between the signal applied to the input transducer and signal sensed by the output transducer.
11. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of measuring viscosity is carried out by measuring the frequency change required for maintaining a constant phase shift of the imparted signal.
12. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, further comprising measuring the fluid temperature.
13. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, further comprising measuring the density of the fluid.
14. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 1, wherein the step of measuring viscosity is carried out by measuring the change in the impedance of a transducer.
15. A method for measuring the shear rate at which the viscosity of a fluid using an acoustic wave device having an input and an output transducers, and being coupled to the fluid for imparting a signal thereto, the method comprising the steps of:
 - imparting a signal of a selected input power level into the input transducer, and measuring an output power level of the harmonic signal from the output transducer;
 - measuring the viscosity of the fluid;
 - calculating the average penetration depth of the signal imparted to the liquid using the input power level, the output power level, the separately-known density, and characteristic of the acoustic wave device construction, to derive the average amplitude of the wave imparted to the liquid; and,

calculating the shear rate of the viscosity measurement using the measured viscosity of the liquid, and the calculated penetration depth.

16. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out by measuring the change in the impedance of a transducer.
17. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is performed utilizing the acoustic wave device.
18. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 17, wherein the step of measuring viscosity is carried out by measuring power insertion loss between the input and output transducers.
19. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out by measuring phase shift of the imparted signal.
20. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out by measuring the frequency change required for maintaining a constant phase shift of the imparted signal.
21. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of calculating the shear rate is carried out by

computing penetration depth of the acoustic wave into the fluid, $\delta = \sqrt{2\eta/\omega\rho}$,

where ω is the radian frequency of the applied harmonic wave having frequency, F, and $\omega=2\pi F$, ρ is the density of the sample liquid, and η is the intrinsic viscosity (Pascal-seconds);

utilizing a design parameter 'C' of the acoustic wave device, to relate a crystal wave displacement 'U', to the average power flow, P_{avg} , as $U = C\sqrt{P_{avg}}$; and,

utilizing the frequency of the imparted signal and the foregoing calculations of the penetration depth and the displacement of the crystal face U , to calculate the shear rate as $\dot{\gamma} = \omega U / \delta$.

22. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of calculating the shear rate is carried out to produce a correlation between the amplitude and the geometric average of the power inserted at the input power and the power sensed at the output transducer.
23. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the selected region contains therewith the geometrical midpoint between the input transducer and output transducer respective geometries.
24. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out utilizing the insertion power loss between the input and output transducers.
25. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out utilizing phase shift between the signal applied to the power transducer and signal sensed by the output transducer.
26. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring viscosity is carried out by measuring the frequency change required for maintaining a constant phase shift of the imparted signal.
27. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, further comprising measuring the fluid temperature.
28. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, further comprising measuring the density of the fluid.
29. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, wherein the step of measuring the viscosity and the step of calculating the average penetration depth use the same set of input and output power levels.

30. A method for measuring shear rate at which the viscosity of a fluid as claimed in claim 15, further comprising the step of utilizing the measured shear rate and associated viscosity results for controlling a manufacturing process or a portion thereof.

31. A method for measuring viscosity of fluid at a desired shear rate, utilizing an acoustic wave device having an input and an output transducers, and having a known relationship between input power, output power, and an acoustic wave amplitude at a selected region between the input and output transducer, the acoustic wave device being coupled to the measured fluid, the method comprising the steps of:

- i. selecting an initial input power level, as an estimated power level;
- ii. applying a harmonic signal having the estimated power level to the input transducer, to impart an acoustic wave of pre-selected amplitude at the selected region;
- iii. using the acoustic wave device, measuring viscosity of the fluid to obtain a measured viscosity at the selected region;
- iv. calculating the actual shear rate of the fluid at the selected region by using the viscosity measurements, and the acoustic wave amplitude;
- v. calculating the difference between the actual shear rate and the desired shear rate to produce a shear rate error;
- vi. adjusting the estimated input power level to compensate for the shear rate error, and
- vii. using the adjusted estimated power level, repeating the steps iii through vi until the shear rate error is within acceptable tolerance from the desired shear rate.

32. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of selecting further comprises the step of estimating the input power level required to impart the desired shear rate to the fluid, and using the estimated power level in the step of applying.

33. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 32, wherein the step of estimating utilizes information relating to the fluid to be measured for estimating the output power at the output transducer.
34. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein in the step of selecting, the estimated power level is being selected randomly.
35. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein in the step of selecting the estimated power level is selected to be about the mid point of the power range applicable to the acoustic wave device.
36. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of measuring the viscosity is carried out by calculating power insertion loss between the input and output transducers.
37. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of measuring the viscosity is carried out by measuring a phase shift between the input and output transducers.
38. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of measuring the viscosity is carried out by a frequency change required to maintain a constant phase shift between the input and output transducers.
39. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of calculating the shear rate is carried out by

utilizing the formula for penetration depth of the acoustic wave into the fluid,

$$\delta = \sqrt{2\eta / \omega \rho} \quad , \text{ where } \omega \text{ is the radian frequency of the applied harmonic wave}$$

having frequency, F, and $\omega = 2\pi F$, ρ is the density of the sample liquid. and η is the intrinsic viscosity (Pascal-seconds),

utilizing a design parameter 'C' of the acoustic wave device to relate the wave displacement 'U', to the average power flow, P_{avg} , as $U = C\sqrt{P_{avg}}$,

and utilizing the frequency of the imparted signal, and the foregoing calculations of the penetration depth and the displacement of the crystal face U, to calculate the shear rate as $\dot{\gamma} = \omega U / \delta$.

40. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of calculating the shear rate is carried out to produce a correlation between the amplitude and the geometric average of the power inserted at the input power and the power sensed at the output transducer.
41. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the selected region contains therewith the geometrical midpoint between the input transducer and output transducer respective geometries.
42. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of adjusting is carried out utilizing a PID algorithm.
43. A method for measuring viscosity of fluid at a desired shear rate as claimed in claim 31, wherein the step of adjusting is carried out by adjusting the power level to obtain a complete cancellation of the error.
44. A method for characterizing viscoelastic properties of a fluid by utilizing an acoustic wave device coupled to the fluid, the device having an input and output transducers, the method comprising the steps of:
 - i. selecting a set of input power levels in accordance within a range of input power levels appropriate to the acoustic wave device;
 - ii. for each of the selected input power levels
 - a. applying the selected input power level to the input transducer;
 - b. measuring an output signal from the output transducer;
 - c. calculating the viscosity of the fluid utilizing the applied input power level and the measured output signal;

- d. calculating the shear rate at which the viscosity measurement occurred, utilizing the applied input power level and the measured output signal.

45. A method for characterizing viscoelastic properties of a fluid as claimed in claim 44, wherein the step of measuring viscosity is carried out by measuring the change in the impedance of a transducer.

46. A method for characterizing viscoelastic properties of a fluid as claimed in claim 44, wherein the input power levels represent a continuum.

47. A method for characterizing viscoelastic properties of a fluid as claimed in claim 44, wherein the step of calculating the shear rate is carried out by

utilizing the formula for penetration depth of the acoustic wave into the

fluid, $\delta = \sqrt{2\eta / \omega \rho}$, where ω is the radian frequency of the applied harmonic

wave having frequency, F, and $\omega = 2\pi F$, ρ is the density of the sample liquid, and η is the intrinsic viscosity (Pascal-seconds);

utilizing a design parameter 'C' of the acoustic wave device, to relate the wave displacement 'U', to the average power flow, P_{avg} , as $U = C\sqrt{P_{avg}}$;

and utilizing the frequency of the imparted signal, and the foregoing calculations of the penetration depth and the displacement of the crystal face U, to calculate the shear rate as $\dot{\gamma} = \omega U / \delta$.

48. A method for characterizing viscoelastic properties of a fluid by utilizing an acoustic wave device coupled to the fluid, the device having an input and output transducers, the method comprising the steps of:

- i. selecting a set of desired shear rates for measuring the fluid viscosity;
- ii. for each of the selected desired shear rates:
 - a. selecting an estimated input power level;
 - b. applying the estimated input power level to the input transducer;

- c. measuring an output signal from the output transducer;
- d. calculating the viscosity of the fluid utilizing the applied input power level and the measured output signal;
- e. calculating the actual shear rate at which the viscosity measurement occurred, utilizing the applied input power level and the measured output signal;
- f. calculating the difference between the actual shear rate and the desired shear rate to produce a shear rate error;
- g. adjusting the estimated input power level to compensate for the shear rate error; and,
- h. using the adjusted estimated power level , repeating the steps b through g until the shear error rate is within acceptable tolerance from the desired shear rate.

49. A method for characterizing viscoelastic properties of a fluid as claimed in claim 48, wherein the input power levels represent a continuum.

50. A method for characterizing viscoelastic properties of a fluid as claimed in claim 48, wherein the step of calculating the shear rate is carried out by

utilizing the formula for penetration depth of the acoustic wave into the fluid, $\delta = \sqrt{2\eta/\omega\rho}$, where ω is the radian frequency of the applied harmonic

wave having frequency, F, and $\omega=2\pi F$, ρ is the density of the sample liquid, and η is the intrinsic viscosity (Pascal-seconds);

utilizing a design parameter 'C' of the acoustic wave device, to relate the wave displacement 'U', to the average power flow, P_{avg} , as $U = C\sqrt{P_{avg}}$;

and utilizing the frequency of the imparted signal, and the foregoing calculations of the penetration depth and the displacement of the crystal face U, to calculate the shear rate as $\dot{\gamma} = \omega U/\delta$.

51. A method for characterizing viscoelastic properties of a fluid as claimed in claim 48, wherein the step of measuring viscosity is carried out by measuring the change in the impedance of a transducer.
52. A method for measuring shear rate at which the viscosity of a fluid is being measured utilizing a single port acoustic wave device having a characteristic relationship between input power and an acoustic wave amplitude, the acoustic wave device having a crystal with at least one face coupled to the fluid to impart an acoustic wave thereto, and having a known relationship between applied power and displacement U of the crystal face, the method comprising the steps of:
- applying harmonic energy signal having a frequency ω to the acoustic device;
 - measuring the input power level of harmonic energy signal;
 - using the characteristic relationship, and the input level, calculating the amplitude of the average acoustic wave imparted to the fluid;
 - measuring viscosity of the fluid in the vicinity of the acoustic wave device, to obtain a measured viscosity δ ; and,
 - calculating the shear rate of the fluid $\dot{\gamma}$ at which the by using the frequency, the viscosity measurement, and the displacement of the crystal face.
53. A method for measuring shear rate as claimed in claim 52, wherein the step of calculating comprise using the formula $\dot{\gamma} = \omega U / \delta$.
54. A method for measuring shear rate as claimed in claim 52, wherein the step of measuring viscosity is performed using phase shift of the harmonic energy signal.
55. A method for measuring shear rate as claimed in claim 52, wherein the step measuring viscosity is performed using impedance measurement of the acoustic wave device.

56. A method for measuring shear rate as claimed in claim 52, wherein the step of measuring viscosity is performed by adjusting the frequency of the harmonic signal.
57. A method for measuring shear rate at which the viscosity of a fluid is being measured utilizing a single port acoustic wave device having a characteristic relationship between input power and an acoustic wave amplitude, the acoustic wave device having a crystal with at least one face coupled to the fluid to impart an acoustic wave thereto, and having a known relationship between applied power and displacement U of the crystal face, the method comprising the steps of:
- feeding harmonic incident signal of frequency ω to an incident port of a directional coupler and measuring the power of the incident signal;
 - coupling a transmission port of the directional coupler to a single port transducer, the transducer being coupled to the fluid to be measured;
 - measuring reflected power at a reflection port of the directional coupler;
 - deriving an acoustic wave device input impedance from the measured incident power and the measured reflected power;
 - calculating the fluid viscosity δ utilizing the input impedance;
 - calculating the shear rate of the fluid $\dot{\gamma}$ at which the by using the frequency, the viscosity measurement, and the displacement of the crystal face.
58. A method for measuring shear rate as claimed in claim 52, wherein the step of calculating comprises using the formula $\dot{\gamma} = \omega U / \delta$.
59. An apparatus for measuring shear rate at which the viscosity of a fluid is being measured, the apparatus comprises:
- a single port acoustic wave device coupled to the liquid;
 - a driving circuitry adapted to provide harmonic signal power;
 - an incident wave power detector coupled to the driving circuitry;

a directional coupler comprising an incident port, a reflection port, and a transmission port coupled to the acoustic device;

a reflected wave power detector coupled to the reflection port;

wherein the incident port being coupled to the driving circuitry and the incident power detector.

60. An apparatus for measuring shear rate as claimed in claim 59, wherein the acoustic wave device having a known relationship between harmonic power signal of frequency ω applied hereto and a displacement of a crystal face, and the step of calculating comprises using the formula $\dot{\gamma} = \omega U / \delta$.